# Efficacy of Bifenthrin Treatment Zones Against Red Imported Fire Ant

A.M. PRANSCHKE,[1] L.M. HOOPER-BÙI,[2] AND BARRY MOSER[3]

Department of Entomology, 404 Life Science Building, Louisiana State University, Baton Rouge, LA 70803

J. Econ. Entomol. 96(1): 98–105 (2003)

**ABSTRACT** Exclusion of ants, particularly red imported fire ant, *Solenopsis invicta* (Buren), from homes, nursing facilities, hospitals, and electrical housings is an important strategy in urban and rural pest control. We conducted a laboratory bioassay to determine the repellency of granular bifenthrin (Talstar: rate 2.087 kg of formulated product/92.88 $m^2$ or 4.6 lb formulated product/1000 $feet^2$ or 4.2 g active ingredient/92.88 $m^2$) to *S. invicta* foragers. In the field, we compared the efficacy of three widths (0.3, 2.0, and 3.0 m) of granular bifenthrin-treated zones at the rate 2.087 kg of formulated product/92.88 $m^2$ and investigated the survival of individual ants successfully crossing the respective zones. Granular bifenthrin was nonrepellent to fire ant foragers in the laboratory. The 2.0- and 3.0-m treatment zones provided 100% protection for 7 wk after treatment and provided a reduction in the number of ants breaching the treated zone compared with the control for the remaining 9 wk of the study. This level of control may be tolerable for homeowners and is, therefore, considered an effective treatment for 15 wk after treatment. Hospitals, nursing homes, and electrical boxes would have to be treated on a monthly or bimonthly to remain ant free.

**KEY WORDS** perimeter treatment, ant exclusion, repellency, granular contact insecticide

INDIVIDUAL MOUND TREATMENTS and broadcast applications for control of red imported fire ant, *Solenopsis invicta* (Buren), are widely used and have been studied extensively (Morrill 1977; Francke 1983; Williams and Lofgren 1983; Lemke and Kissam 1987; Collins et al. 1999). Insecticidal barriers are commonly used by homeowners and pest management professionals to prevent ants from entering structures. Rust et al. (1996) and Klotz et al. (2003) investigated the use of insecticide sprays as perimeter treatments for Argentine ants, *Linepithema humile* (Mayr). Perimeter treatments with granular contact insecticides have not received as much attention. Oi et al. (1996) used two baits, a spray, and granular 2% Diazinon (1.5-m barrier) against Pharaoh ant, *Monomorium pharaonis* L., succeeding only with baits.

Attraction of fire ants to electrical fields has resulted in infestations of electrical equipment, causing failure and damage (Mackay et al. 1992a). Fire ants have entered nursing homes and stung elderly bed-ridden individuals in Mississippi and Louisiana. A typical barrier treatment consists of applying a contact insecticide, such as a pyrethroid and organophosphate, to the ground surface adjacent to a structure to prevent insect entrance to that structure. A barrier treatment can range in width from 0.3 to 3.0 m with most insecticide labels suggesting an application width of 1.5 to 3.0 m (5 to 10 ft) for pest management professionals. Published data regarding effectiveness of barrier treatments for fire ant control are limited and recommendations of application width also are lacking.

A chemical barrier does not have to kill ants to prevent entrance to a structure (Rust et al. 1996). Insecticide repellency has traditionally been thought to be a good characteristic of insecticides used for barriers. However, Oi and Williams (1996) demonstrated the lack of repellency of bifenthrin (a type I pyrethroid) in potting soil to fire ant colonies. They determined residual levels needed for quarantine enforcement of nursery stock. Even though bifenthrin has been shown to be nonrepellent in some field situations, the labeled product recommends treatment of a 6 to 10 ft (2 to 3 m) barrier. We used the term treatment zone rather than barrier treatment because of the potential nonrepellent properties of bifenthrin, in which case it may not function as a barrier.

The objectives of this study were to determine the (1) repellency of bifenthrin as a barrier treatment to *S. invicta* foragers; (2) effectiveness of 0.3-, 2.0-, and 3.0-m zone treatments with the granular contact insecticide Talstar PL Granular (FMC Corp., Philadelphia, PA; 2.087 kg of formulated material/92.88 $m^2$, 4.6 lb of formulated product/1000 $ft^2$, or 4.2 g of active ingredient/92.88 $m^2$); and (3) survival of individuals crossing each of those zone applications.

[1] USDA–ARS BCMRRU, P.O. Box 225, 141 Experiment Station Road, Stoneville, MS 38776.

[2] E-mail: Lhooper@agctr.lsu.edu.

[3] Department of Applied Statistics, Louisiana State University, Baton Rouge, LA 70803.

## Materials and Methods

**Test for Bifenthrin Repellency.** A laboratory bioassay, with both a dry and wet application, was conducted to determine whether applications of bifenthrin are repellent to fire ant foragers. The experimental unit consisted of three plastic containers (8 length by 18 width by 4 cm height; Pioneer Plastics, Phoenix, AZ) that were hot glued together in an "H" design. The interior sides of the containers were coated with Teflon (DuPont, Wilmington, DE). Wooden bridges constructed from 2-mm diameter dowels enabled ants to enter the second and third compartments. Bridges were 3.5 cm in length and 5.5 cm in height, passed over the adjoining walls, and were anchored with hot glue or modeling clay. The bridges exceeded the height of the containers by 1.5 cm to facilitate ant movement between containers while preventing escape. A dead cricket and ≈1 g of Armour Vienna sausage was placed in the third compartment (food container), which was furthest from the nest (first) container, to stimulate foraging of the ants.

All ants for the experiment were taken from five well-fed laboratory colonies. Ants were starved for 36 h before the experiment. One hundred forager ants were placed in the first compartment (nest container) of each replicate and provisioned with water. A bridge between the first and second compartments (second container is to be the treated container) was not initially installed to restrict ant movements to the holding container so no foraging trails were established. After the starvation period and treatment of the second container, a bridge connecting the first and second compartments was installed with a small amount of modeling clay.

Three treatments were evaluated in this study: an untreated control, a dry application of Talstar PL Granular (0.2% bifenthrin; FMC Corp.), and a wet application. In the control, the second compartment was empty. For the dry application treatment, bifenthrin was applied according to the label at the high rate, 0.3 g/144 $cm^2$ (2.087 kg formulated material/92.88 $m^2$, 4.6 lb of formulated product/1000 $ft^2$, or 4.2 g of active ingredient/92.88 $m^2$) to the second compartment. The granules were applied through a wire mesh screen to allow even distribution over the surface. The bridges were connected immediately after the dry application of insecticide. For the wet application, 2 ml of water was pipetted into the bifenthrin in the second compartment to simulate "watering in" in which water is applied after application to facilitate bifenthrin transfer from the granules to the substrate. The water-bifenthrin mixture was evenly distributed on the bottom of the compartment by quickly shaking the container back and forth horizontally. The containers were placed in an exhaust hood to dry overnight, and the study was performed the next day. After drying, granules were removed from the compartment by inverting the container and lightly tapping the bottom. Repellency was considered present if the ants crossing the first bridge did not step onto the treated surface of the second container. Ants were allowed 1 h from the onset of the experiment to cross into the treated containers. Ant presence in the second and third containers was recorded at 10 min, 30 min, and 1 h.

The experiment was conducted as a completely randomized design with 15 replicates per treatment. Chi-square analysis was used to compare forager presence in the second compartment among the control and both treatments.

**Test for Zone Breaching and Survival.** A field study was initiated in July 2000 at the Louisiana State University Agricultural Center's Burden Research Plantation, Baton Rouge, LA, to determine effectiveness of 0.3-, 2.0-, and 3.0-m zone treatments using the granular contact insecticide bifenthrin (2.087 kg of formulated material/92.88 $m^2$, 4.6 lb formulated product/1000 $ft^2$, or 4.2 g active ingredient/92.88 $m^2$) and the survival of individuals crossing each of these zone applications. The study site consisted of an open area enclosed by pine trees and contained a perimeter circular gravel drive. St. Augustine grass, *Stenotaphrum secundatum* (Walt.) Kuntze was the predominant ground cover. Between the gravel drive and the tree line, ornamental trees and shrubs landscaped the understory serving as an environmental transition zone. For at least 1 yr before the study, the site was not subjected to any insecticide-based *S. invicta* control strategies.

To determine the efficacy of bifenthrin granular insecticide as a zone treatment, four sample locations were established, one at each of the cardinal directions, between the drive and the tree line. Three control plots were established in the same area but in the northern portion of the area where they were separate from the treatments to completely avoid any interference with bifenthrin application. Each location (= replicate: west, east, south) contained three treatments: 0.3-, 2.0-, and 3.0-m radius. All of the sample locations were similar in topography, temperature, humidity, ground cover, and shade. The circles (= plot) were used to simulate a zone treatment that might be applied around a structure or electrical box. Treatments were separated by a minimum of 26 m, which was designed to minimize foragers walking across multiple treatments. Plot centers were marked using an 8 cm-long nail with a florescent orange painted plastic cap staked flush with the ground. Using a string premeasured at the desired radius length, brown Color Place spray paint (Wal-mart Stores, Bentonville, AR) was used to mark a temporary outline of each circle. Treatment of the circles is described below.

Ants were collected using four food traps per plot. Each food trap consisted of a 20-ml screw cap scintillation vial containing ≈1 g of Armour Vienna sausage. Food traps were placed in the center of each circle in a cross-like manner with the opened ends facing outward to encourage fire ants foraging 360°. A 900 $cm^2$ plywood cover wrapped in aluminum foil was placed over the vials to prevent direct sunlight from heating the traps. Traps were collected after 1 h. Ants were trapped inside the vial by replacing the screw cap. Vials were immediately transported to the laboratory, and ants from one vial per treatment were placed into a 26 × 32 × 10-cm covered holding container, coated with Teflon to prevent ants from escaping. If a trap contained <100 ants, additional foragers that crossed a zone of the same size were monitored separately. These additional observations were done to reduce large mortality calculations resulting from small sample size. The remaining ants were killed and stored at −84°C for counting at a later date. In addition, to the sausage from the trap, a water vial was placed into each container to minimize mortality as a result of desiccation or starvation. The ants were monitored for mortality at 1-, 2-, 4-, 8-, 12-, and 24-h postcollection. At the conclusion of the mortality study, all ants were counted and recorded to obtain percentage of mortality.

Before treatment, ants numbers were monitored in food traps for 3 wk. Food traps were placed in the circles by 0930 hours from 8 June 2000 through 25 October and by 1430 hours from 31 October to 3 December. Kidd and Apperson (1984) determined that peak foraging activity by *S. invicta* was between 0900 and 1100 hours from July to September. The sampling objective was to encourage breaching to determine earliest zone breakdown time. Sampling times needed to be adjusted in the later stages of the study to avoid low ant numbers as a result of early morning cool temperatures and morning dew in the late season. On 10 July, bifenthrin was applied at the recommended high application rate of 2.087 kg of formulated material/92.88 $m^2$ (4.6 lb/1000 $ft^2$) or 6.6, 276.9, and 623.1 g for circles with radius lengths 0.3, 2.0, and 3.0 m, respectively, by using a shaker. The shaker consisted of a 400-ml cylindrical plastic container with five 0.5-cm diameter holes in the lid. The shaker method allowed consistent application of insecticide granules within the desired area to be treated. The entire area of the circle was treated including the area where the food traps were placed. The study site was maintained by the Burden Research Plantation's grounds crew who mowed the grass to a height of ≈25 mm once every 2 wk.

**Data Analyses.** Statistical analysis of sample population means over time was not used because *S. invicta* foragers failed to successfully cross many of the treated plots after bifenthrin application. The number of zeros obtained for ant counts after treatment caused problems in data analyses. Logistic analyses using GENMOD Procedure (SAS Institute 1999) and Chi-square analysis was applied to the presence-absence proportions of fire ant forager sample populations within each of the treatments. To increase sample size for presence-absence, three post-treatment time group intervals were established. Post-treatment time group one contained samples from the first 5 wk after insecticide application. Time group two contained samples from week six through 10. Time group 3 contained samples from week 11 through 15. Chi-square *P* values with Bonferronni adjustments were reported for all analyses testing treatment comparisons. LIFETEST Procedure (SAS Institute 1999) was used for survival curve comparisons of sample populations over the 24 h after collection monitoring. Fire ant forager survival at 24 h after collection was performed with LOGISTIC Procedure (SAS Institute 1999). Analyses were conducted with SAS 8.02 (SAS Institute 1999).

## Results

**Test for Bifenthrin Repellency.** Repellency did not occur with either treatment. After 10 min, foragers were not repelled by the presence of bifenthrin in either application ($\chi^2 = 2.4$; df = 2; $P > 0.05$). Foragers entered the second compartment in 53% (8 of 15), 67% (10 of 15), and 80% (12 of 15) of the untreated control, dry, and wet applications, respectively. Individuals traveling over the insecticide showed signs of impairment, either prostrate or convulsing symptoms, within 10 min of contact with bifenthrin. Individuals who could not right themselves were considered dead.

Thirty minutes after treatment, fire ant foragers occupied 100% of the treated compartments in both bifenthrin applications and 93% (14 of 15) of the untreated compartments in the control, indicating treatment homogeneity ($\chi^2 = 2.07$; df = 2, $P > 0.05$). At this time, fire ant foragers were also observed in the third compartment, 60% (9 of 15), 27% (4 of 15), and 47% (7 of 15) of the untreated control, dry and wet bifenthrin applications, respectively. For each replicate in either treatment, a maximum of four ants was observed in the third compartment. In those treatments, ants observed in the third compartment were dead and no ants were found feeding on the food source. Ants observed in the third compartment of the untreated control showed active movement on and around the food source.

After 1 h, there was no change in the number of second and third compartments occupied for any treatment, and the observations were terminated. After 24 h, 100% mortality was observed in both bifenthrin treatments. Foragers were not repelled by the treatment at any observation time during the study.

**Test for Zone Breaching and Survival.** Rainfall for July, August, and September 2000 was 14.55, 9.14, and 10.19 cm, respectively. The 0.3-m zone never provided 100% protection to the food vials with 50% of the 0.3-m plots breached within 2 wk after treatment. However, the 0.3-m zone treatment exhibited an initial suppression in the sample population 2 wk after treatment, providing an average 98 (week 1) and 87% (week 2) reduction, in the mean number of ants compared with the contemporaneous untreated controls (Fig. 1). At week three after treatment, the mean number of ants that breached the treatment was 27% less than the concurrent controls, reaching the before treatment mean (896 ± 157, mean ± SE).

Initial breaching of 2.0-m plots occurred 7 wk after treatment (Fig. 2). For the remaining 9 wk of the study, 48% (13 of 27, observations were totaled over the final weeks of the study) of the plots were breached compared with 89% (24 of 27) in the untreated control. One treated plot was not breached until 10 wk after insecticide application. Fire ant foragers did not breach the 3.0-m zone for 7 wk after treatment (Fig. 3). All three 3.0-m plots were breached immediately after the 7-wk period. For the

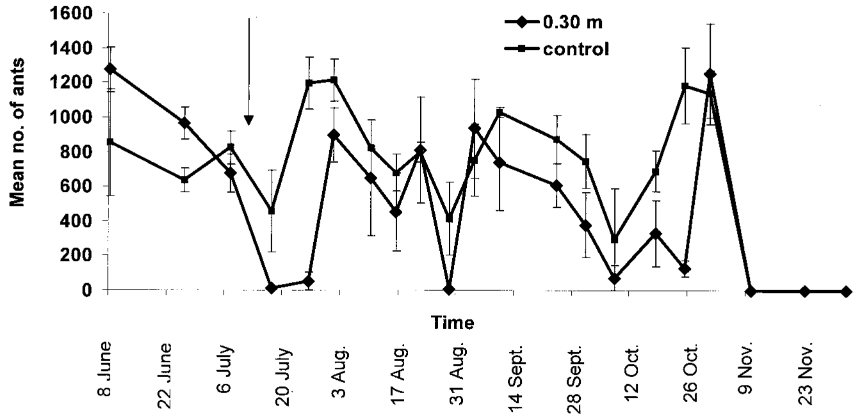


**Fig. 1.** Mean number of ants measured weekly from eight June to 23 November in the 0. 30-m zone treatment versus untreated control (UTC) at Burden Research Plantation, 0.2% bifenthrin (Talstar) applied 10 July 2000 (arrow). Solid diamonds represent bifenthrin treatments and squares represent UTC.

remaining 8 wk of the study, 38% (9 of 24) of the plots were breached with no single plot breached more frequently than another.

The final 3 wk of the study (17 and 23 November and 3 December) were not included in the analysis because fire ant foragers failed to reach the food traps in all treatment and untreated control plots. Low seasonal temperatures probably contributed to the absence of ants at the food traps.

Analysis with GENMOD Procedure provided evidence of a treatment and time group interaction ($\chi^2 = 4.54$; df = 1; $P < 0.05$). The efficacy of treatments changed through time. Contingency table analysis of ant presence in both untreated control and 0.3-m zone treatment were found to be homogeneous ($\chi^2 = 1.51$ and 3.12, respectively; $P = 0.68$ and 0.37, respectively) over the time groups, whereas, presence of ants in the 2.0- and 3.0-m zone treatments were not significant ($\chi^2 = 23.63$ and 22.06, respectively; $P < 0.0001$ and 0.0001, respectively), indicating a treatment effect through the duration of the study.

Proportions of plots breached in the untreated control ranged from 0.93 to 0.87 in time groups 1, 2, and 3 (time groups 1 to 5, 6 to 10, and 11 to 15 wk), respectively. Breach of the 0.3-m zone exceeded 70% in the first time group with more plots (87%) breached in the second time group. No significant differences in the proportions of breaches between the control and the 0.3-m zone were found at any time. No breaches were observed in either 2.0- or 3.0-m zones during the first 5 wk after insecticide application. Both the 2.0- and 3.0-m width treatments were breached 40% of the time (6 of 15, observations were totaled for each treatment within time group 2) during the second time group. The final time group had a slight increase in breaches to 46% (7 of 15, observations were totaled within time group 3) for the 2.0-m zone and a decrease to 20% (3 of 15) for the 3.0-m zone. In the last time group, the 2.0-m zone was not significantly different from any treatment or control. Chi-square $P$ values for each time interval are reported in Table 1.

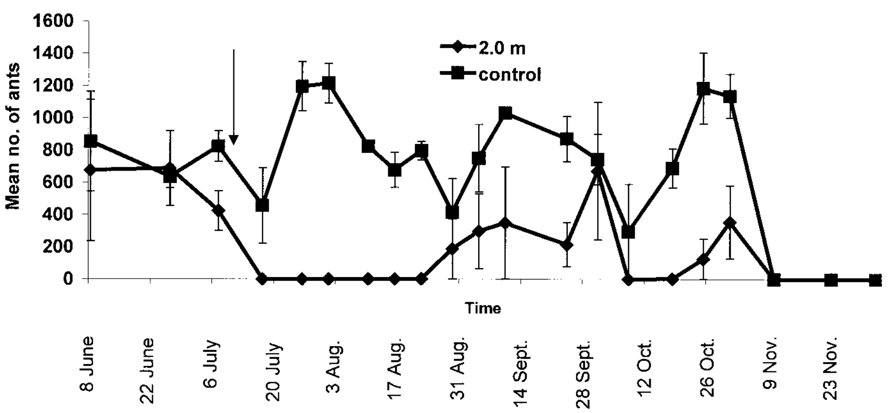


**Fig. 2.** Mean number of ants measured weekly from eight June to 23 November in the 2. 0-m zone treatment versus untreated control (UTC) at Burden Research Plantation, 0.2% bifenthrin (Talstar) applied 10 July 2000 (arrow). Solid diamonds represent bifenthrin treatments and squares represent UTC.

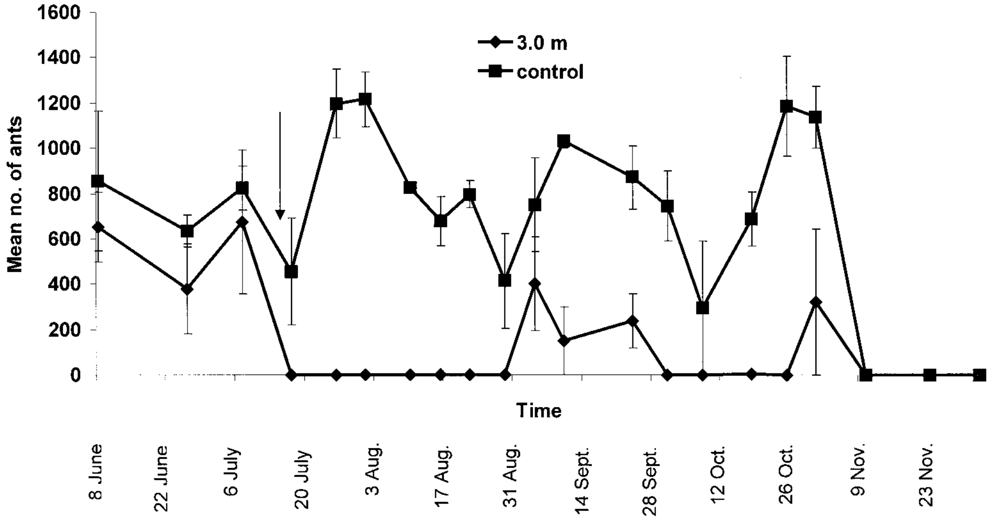


**Fig. 3.** Mean number of ants measured weekly from eight June to 23 November in the 3. 0-m zone treatment versus untreated control (UTC) at Burden Research Plantation, 0.2% bifenthrin (Talstar) applied 10 July 2000 (arrow). Solid diamonds represent bifenthrin treatments and squares represent UTC.

Mean number of ants per breach within each time group for all three zone treatments are represented in Fig. 4. After the first 5 wk after treatment, a significant difference in mean ant numbers was only found between the 0.3- and 3.0-m treatment (*t*-test; $P < 0.05$). No significant differences in ant numbers among the treatments were found during the final time group (analysis of variance [analysis of variance (ANOVA)]; $P > 0.05$). High variability in the number of ants at a food trap, for any particular breaching event, was observed throughout the study. For example, during the last time group, the 3.0-m treatment was breached three times with ant numbers of 2, 19, and 964 (328 ± 318, mean ± SE).

**Table 1. *P* values from chi square likelihood ratio test for comparisons of bifenthrin zones (0.3, 2.0, 3.0 m) and untreated control at time group 1 (wk 1–5) after treatment**

| | Control | 0.3 m | 2.0 m | 3.0 m |
|---|---|---|---|---|
| Time group 1 (wk 1–5) | | | | |
| Control | 0.3295 | <0.001* | <0.001 | |
| 0.3 m | | | <0.001 | <0.001 |
| 2.0 m | | | | NA |
| 3.0 m | | | | |
| Group 2 (wk 6–10) | | | | |
| Control | | 1.0000 | 0.0052 | 0.0052 |
| 0.3 m | | | 0.0063 | 0.0063 |
| 2.0 m | | | | 1.0000 |
| 3.0 m | | | | |
| Group 3 (wk 11–15) | | | | |
| Control | | 1.0000 | 0.0502 | <0.001 |
| 0.3 m | | | 0.0547 | 0.0028 |
| 2.0 m | | | | 0.2451 |
| 3.0 m | | | | |

NA, not applicable.

* Each *P* value was compared with a Bonferronni adjustment to determine significance (*P* value/no. comparisons, 0.05/6 = 0.008), i.e., 0.001 < 0.008 therefore significant.

We monitored the survival of collected ants at 24 h after sampling of each treatment. The 0.3-m treatment resulted in 12.1% (4 of 33) survival in the first week after insecticide application, the lowest survival of all treatments for any week after treatment. The first breach in the 2.0-m zone resulted in 79.6% (70 of 88) survival, whereas the first breach in the 3.0-m treatment contained 96.5% forager survival at 24 h after collection. Both treatments, 0.3 m at week 1 after insecticide treatment and 2.0 m at week 7 after treatment, contained the lowest number of individuals captured for monitoring survival 8 wk after insecticide application. Mortality was highest for those two sample populations compared with other samples. Untreated control survival ranged from 92.7 to 100% throughout the study.

Logistic Procedure Analysis to test date effects and date-treatment interactions at 24 h after collection indicated a date effect in the survival of fire ants when exposed to any of the treatments throughout the study ($\chi^2 = 6.1$, df = 1, $P < 0.05$). Furthermore, a date-treatment effect was also found ($\chi^2 = 28.3$, df = 3, $P < 0.0001$). Because of the sensitivity of the test, low sample population, and high mortality in week one of the 0.3-m treatment, $n = 33$ and 88.9%, respectively, a second analysis was run without week 1 after treatment data. Date of post-treatment monitoring of mortality was no longer found to affect these data ($\chi^2 = 2.41$; df = 1; $P > 0.05$). However, a date-treatment interaction was still found ($\chi^2 = 25.62$; df = 3; $P < 0.0001$). This was not unexpected because ant breaching was variable for the 2.0- and 3.0-m zones.

Lifetest Procedure Analyses indicated heterogeneity of survival among the treatments over 1, 2, 4, 8, 12, and 24 h after collection monitoring during the study (Wilcoxon $\chi^2 = 61.3$; df = 3; $P < 0.0001$). The number of individuals that died varied over the hours moni-

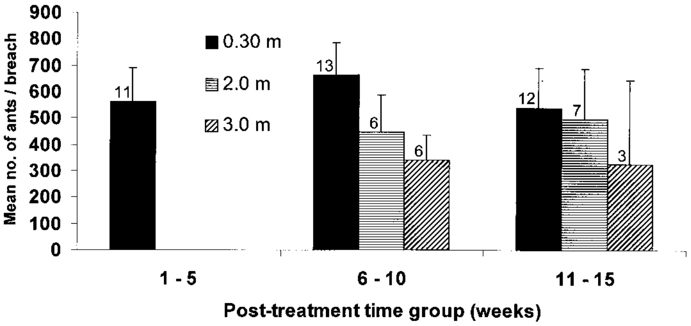


**Fig. 4.** Mean number of *S. invicta* foragers per breach for 0.3-, 2.0-, and 3. 0-m zone treatments of bifenthrin located at Burden Research Plantation. Numbers above each bar represent number of breaches for that time group.

tored after collection among the treatments and untreated control. In general, mortality in the control was not observed until 8 h after collection, whereas mortality in any of the treatments was initially observed before 8 h after collection.

Survival curves for the 0.3-m zone treatment and control were significantly different (Wilcoxon $\chi^2$ = 157.235; df = 1; $P < 0.0001$) for the first week after treatment (Fig. 5). Forager mortality in the control was not observed until 8 h after collection, whereas, the 0.3-m treatment caused 88% mortality in the forager sample population by 8 h. Although survival curves for week two sampling of the control and 0.3-m treatment were significantly different (Wilcoxon $\chi^2$ = 13.673; df = 1; $P = 0.002$), both treatments contained >90% survival. The number of foragers that breached the 0.3-m treatment increased from 33 to 157 in the second week.

Survival curves for the 2.0-m treatment and concurrent control were significantly different (Wilcoxon $\chi^2$ = 28.575; df = 1; $P < 0.0001$) at 7 wk (Fig. 6). Survivability of the foragers that crossed the 2.0-m treatment decreased to 95% by 2 h and to 79% by 24 h after collection. No significant difference between the survival curves for the control and the 2.0-m treatment during 8 wk (second week of breaching for the 2.0-m treatment) after treatment (Wilcoxon $\chi^2$ = 4.308, df = 1, $P = 0.230$).

The survivability of foragers breaching the 3.0-m zone in week eight after treatment was not significantly different from the control (Wilcoxon $\chi^2$ = 2.419, df = 1, $P = 0.1199$) with >95% survival in both. Survival of foragers that breached the 3.0-m treatment in week nine was greater than the survival of individuals in the control.

## Discussion

Pyrethroids are repellent to some insects. Bifenthrin manufacturer directions for application instruct distribution of the product over a moistened surface. Fire ant foragers readily crossed both dry and wet applications of bifenthrin in this study. Foragers readily traveled over the treated surfaces. Oi and Williams (1996) tested multiple concentrations of bifenthrin to assess its ability to prevent colonization by *S. invicta* in pots. They defined infestations by the presence of a queen, workers, and brood, or large aggregations of workers in or directly adjacent to the pots containing moistened potting soil treated with 0.2% bifenthrin. The pots were exposed to fire ant colonies for 48 h. Sixty-four percent of uninfested pots contained ≈10 worker ants. Our laboratory data corroborate Oi and Williams (1996) observation that fire ant individuals were not repelled. Field applications were expected to follow similar trends. The zones

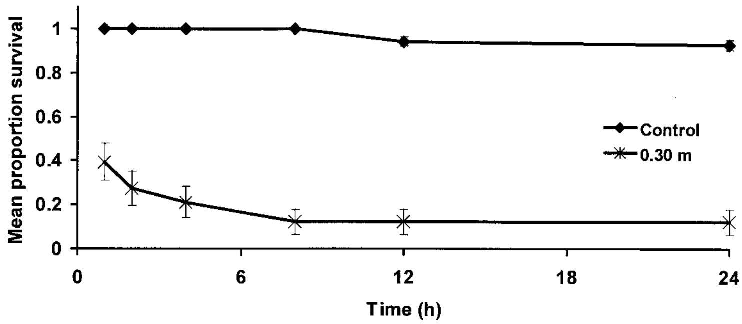


**Fig. 5.** Mean survival curves (proportion of survival of *S. invicta* sample populations) over 24 h after collection for 0. 3-m bifenthrin zone treatment and untreated control at 1 wk after treatment. Control is represented by closed diamonds and the 0. 3-m treatment is represented by asterisks.

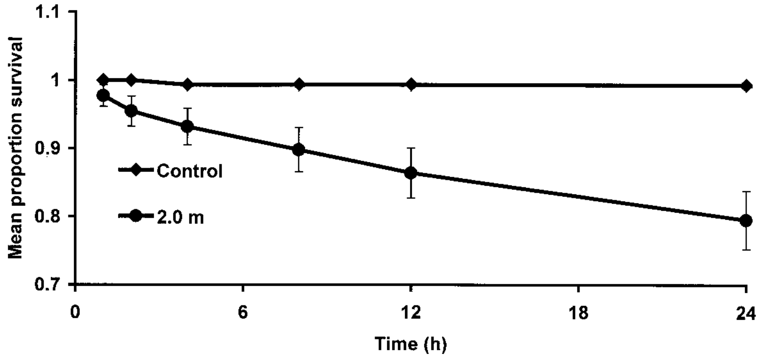


**Fig. 6.** Mean survival curves (proportion of survival of *S. invicta* sample populations) over 24 h after collection for 2. 0-m bifenthrin zone treatment and untreated control at 7 wk after treatment. Control is represented by closed diamonds and 2. 0-m treatment is represented by closed circles.

tested at Burden Research Plantation were relatively small. *Solenopsis invicta* colonies did not infest the treated or control areas. Wiltz (1996) showed fire ant reestablishment (mound presence) began 14 to 35 d after a 0.09-ha (17.4-m radius) area was treated with abamectin and permethrin; however, only one size area was treated.

The 0.3-m zone treatment was ineffective for fire ant suppression >2 wk. The 2.0- and 3.0-m zone treatments prevented breaching for at least 6 wk and subsequent suppression of fire ant activity for at least an additional 9 wk. Prevention of complete breach indicates that bifenthrin is efficacious but does not necessarily indicate that it is repellent. The bifenthrin zone may kill forager scouts and subsequently foraging trails are not formed. At termination of the study, complete treatment breakdown could not be determined for the 2.0- or 3.0-m treatments. However, > 15 wk of fire ant suppression was obtained in the 2.0- and 3.0-m treatments. The breaching percentage in the 2.0-m treatment increased 6% from time group 2. Because only a few ants breached, this may be below a tolerance level for homeowners (but not to nursing homes and hospitals) and is therefore, considered an effective treatment for 15 wk after treatment.

A 0.3-m zone would provide minimal protection against infestations and foragers and would not be a suggested treatment for most applications. The 3.0-m zone would provide maximum fire ant relief for ≈7 wk, then reapplication of the zone may be necessary if there is no tolerance for ants.

Both the 2.0- and 3.0-m zones showed intermittent breaching and varied levels of ant numbers in the food traps after the initial prevention period. Residual effect (half-life) of bifenthrin is known to range from 7 d to 8 mo depending on soil type and concentration (EXTOXNET 1995). The soil types in the treated and control areas are similar and the treatment concentration was the same, so the degradation of bifenthrin should have been constant. Red imported fire ant foragers may not have been repelled by bifenthrin, and it is unlikely that the chemical had undergone accelerated breakdown for the 0.3-m treatment. The foragers probably breached the 0.3-m treatments by using grass blades or fallen pine needles as bridges over that short distance of treated soil more rapidly compared with the 2.0- and 3.0-m zones. The grass at Burden Research Plantation was cut once every 2 wk. Grass clippings were allowed to settle on the ground. An increased frequency in grass cuttings may reduce treatment efficacy. Foragers have a shorter distance to establish a bridge network in the 0.3-m zone to reach the food traps. Moreno et al. (1987) used a barrier of granular diazinon to prevent *L. humile* from foraging in citrus trees and discussed minimal granular insecticide barrier efficacy, relating ants bridging into the trees by unpruned limbs touching the ground surface and weed presence under the canopy. Although the amount of diazinon used in their study was reported, application was described as uniform distribution around the trees but no mention of the width of their barrier was made. The extent to which the foragers are both bridging and contacting bifenthrin within the treated plots in the study at Burden Research Plantation is unknown.

Subterranean foraging tunnels may have contributed to the breaching of the zones. Foraging tunnels provide a means of escape from environmental hazards such as inclement weather while maintaining maximum use of territory. Even under standing water, *S. invicta* foragers were able to use tunnels and continue seeking prey (Showler et al. 1990). Despite 3 d of flooding (4 cm in depth), foragers were continuously monitored at a bait station located opposite a moat. From their nest, a similar means of using tunnels to breach insecticide zones may be possible. Observations on the amount of bridging or tunneling across the radius of a circle were not monitored. Detailed inspections of how plots are breached may answer questions regarding bifenthrin degradation and effects of sublethal exposures on locating food sources.

Survival of fire ants reaching the food traps increased after the first week of breaching may indicate adaptation in foraging methods to avoid mortality associated with chemical exposure. For example, high mortality (88%) was observed in foragers crossing the 0.3-m zone at week one after treatment. Observed mortality in foragers during week 2 decreased to 6%. Furthermore, the 2.0-m zone resulted in 20 and 2% mortality for the first and second breaching dates, respectively. Nonacs (1990) showed reduced exploitation of a food resource in response to a mortality risk along a foraging trail of the ant *Lasius pallitarsis* Provancher. After encountering the risk factor, a *Formica subnuda* (a dominant ant species) individual placed along the foraging trail, foraging was delayed or ceased after individuals encountered the risk. The ants failed to recruit nestmates to the food item. Although mortality risk in that experiment was based upon a biological factor, contact with chemicals also may pose a risk to foragers, negatively affecting nestmate recruitment. Regardless, if the risk is biological or chemical, ant foragers can have a behavioral change in the foraging activity.

Bifenthrin (type I pyrethroid) is also known to have a negative temperature coefficient, with greater efficacy at lower temperatures (EXTOXNET 1995). The final 3 wk of the 19 wk after treatment monitoring occurred during cold weather ($\approx$9°C) adversely affecting fire ant foraging capabilities. Cooler temperatures later in the season may increase treatment efficacy of the degrading chemical to a suboptimum level (an efficacy level below that of application date) providing additional control, as possibly seen with the intermittent breaching in the 3.0-m zone treatment. The number of breaches in the last time group decreased by half compared with the second time group, however, the mean number of ants trapped in the 3.0-m treatment remained constant.

Barrier treatments may be considered a localized application of a broadcast where the application of the insecticide is restricted to an area immediately surrounding a structure. To increase the nonbreaching time after treatment, a larger zone width is recommended or broadcast treatment of bifenthrin in the turf area, and in sensitive areas, a repellent barrier would be better. Although standard applications of zones range in width 1.5 to 3.0 m (5 to 10 feet), a homeowner may apply a zone width not exceeding 0.3 m (1 ft). Once a zone is breached, ant numbers may be highly variable, thereafter, dependent upon environmental conditions. Survival of those foragers crossing the insecticide zone is often >95%. Therefore, if fire ants are observed breaching a zone, mortality of those individuals is exceedingly low, enabling continued recruitment of nestmates to a food source or increased infestations or foragers in protected structures.

## Acknowledgments

This work was supported by the Griffin LLC Graduate Student Fellowship, the Louisiana Department of Agriculture and Forestry, and by FMC Corporation. We acknowledge the support of the Louisiana State University Agricultural Center. We thank two anonymous reviewers and Jessica Rosson (LSU) for their review and constructive comments.

## References Cited

**Collins, H., A-M. A. Callcott, A. Ladner, L. McAnally, and S. Wade. 1999a.** Evaluation of fipronil for control of imported fire ants in turfgrass. Accomplishment Report. Gulfport plant protection station, Center for plant health science and technology, Plant protection and quarantine, U.S. Department of Agriculture.

**EXTOXNET. 1995.** Extension toxicology network: Pesticide information profiles. (http://ace.orst.edu/cgi-bin/mfs.01/pips/bifenthr.htm?28).

**Francke, O. F. 1983.** Efficacy tests of single mound treatments for control of red imported fire ants *Solenopsis invicta* Buren. Southwest. Entomol. 8: 42–45.

**Kidd, K. A., and C. S. Apperson. 1984.** Environmental factors affecting relative distribution of foraging red imported fire ants in a soybean field on soil and plants. J. Agr. Entomol. 1: 212–218.

**Klotz, J. H., M. K. Rust, H. S. Costa, D. A. Reierson, and K. Kido. 2003.** Strategies for controlling Argentine ants (Hymenoptera: Formicidae) with sprays and baits. J. Agric. Urban Entomol. (in press).

**Lemke, L. A., and J. B. Kissam. 1987.** Evaluation of various insecticides and home remedies for control of individual red imported fire ant colonies. J. Entomol. Sci. 22: 275–281.

**Mackay, W. P., S. Majdi, J. Irving, S. B. Vinson, and C. Messer. 1992a.** Attraction of ants (Hymenoptera: Formicidae) to electric fields. J. Kans. Entomol. Soc. 65: 39–43.

**Mackay, W. P., S. B. Vinson, J. Irving, S. Majdi, and C. Messer. 1992b.** Effect of electrical fields on the red imported fire ant (Hymenoptera: Formicidae). Environ. Entomol. 21: 866–870.

**Moreno, D. S., P. B. Haney, and R. F. Luck. 1987.** Chloropyrifos and diazinon as barriers to Argentine ant (Hymenoptera: Formicidae) foraging on citrus trees. J. Econ. Entomol. 80: 208–214.

**Morrill, W. L. 1977.** Red imported fire ant control with diazinon and chlorpyrifos drenches. J. Ga. Entomol. Soc. 12: 96–100.

**Nonacs, P. 1990.** Death in the distance: mortality risk as information for foraging ants. Behavior 112: 23–35.

**Oi, D. H., K. M. Vail, and D. F. Williams. 1996.** Field evaluation of perimeter treatments for Pharaoh ant (Hymenoptera: Formicidae) control. Fla. Entomol. 79: 252–263.

**Oi, D. H., and D. F. Williams. 1996.** Toxicity and repellency of potting soil treated with bifenthrin and tefluthrin to red imported fire ants (Hymenoptera: Formicidae). J. Econ. Entomol. 89: 1526–1530.

**Rust, M. K., K. Haagsma, and D. A. Reierson. 1996.** Barrier sprays to control Argentine ants (Hymenoptera: Formicidae). J. Econ. Entomol. 89: 134–137.

**SAS Institute. 1999.** SAS Version 8.02. Cary, NC.

**Showler, A. T., R. M. Knaus, and T. E. Reagan. 1990.** Studies of the territorial dynamics of the red imported fire ant (*Solenopsis invicta* Buren, Hymenoptera: Formicidae). Agric. Ecosys. Environ. 30: 97–105.

**Williams, D. F., and C. S. Lofgren. 1983.** Imported fire ant (Hymenoptera: Formicidae) control: Evaluation of several chemicals for individual mound treatments. J. Econ. Entomol. 76: 1201–1205.

**Wiltz, B. A. 1996.** Fire ant re-establishment in grass habitats after treatment with insecticides. MS Thesis, Louisiana State University, Baton Rouge, LA.

*Received for publication 5 October 2001; accepted 18 June 2002.*